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## Continuum Spectra of Deuterons for the $p+{}^3\text{He}$ Reaction at 65 MeV

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Continuum spectra of deuterons from  ${}^3\text{He}$  by protons have been measured. The angular distributions of the differential cross sections and the analyzing powers for the continuum spectra in the pp FSI region were obtained. The angular distribution of the cross sections for the FSI region is similar to the one for the  ${}^3\text{H}(p,d){}^2\text{H}$  reaction.

**KEY WORDS:** Helium-3/ Breakup Reaction/ Angular distribution/  
Analyzing power/

### 1. INTRODUCTION

$p+{}^3\text{He}$  system is one of the simplest four nucleon system and very important system for studying three nucleon problem as regards  ${}^3\text{He}$  breakup reaction. Recently, proton continuum spectra from  ${}^3\text{He}$  by protons were studied in other paper<sup>1)</sup>. In that study, the pd final state interaction (FSI) was investigated and the angular distribution of the differential cross sections and the correlation function were explained well by using the multiple scattering calculation including to double scattering terms. The angular distribution of the cross sections was quite similar to the one for the  ${}^2\text{H}(p,p){}^2\text{H}$  scattering, not to the one for the  ${}^3\text{He}(p,p){}^3\text{He}$  scattering. It suggested the first step of this reaction is the pd interaction and the FSI between another proton and deuteron occurs sequentially.

In the present study, deuteron spectra from  ${}^3\text{He}$  by protons were measured. Here the residual nucleus is di-proton. Similar discussions as proton spectra were done.

### 2. EXPERIMENTAL PROCEDURE

65 MeV polarized proton beam was accelerated by the AVF cyclotron at the Research Center for Nuclear Physics (RCNP) of Osaka University. Fig. 1 shows the experimental setup. In the upstream of the beam, a polyethylene target was mounted in a small chamber and the beam polarization was monitored with NaI(Tl) counters

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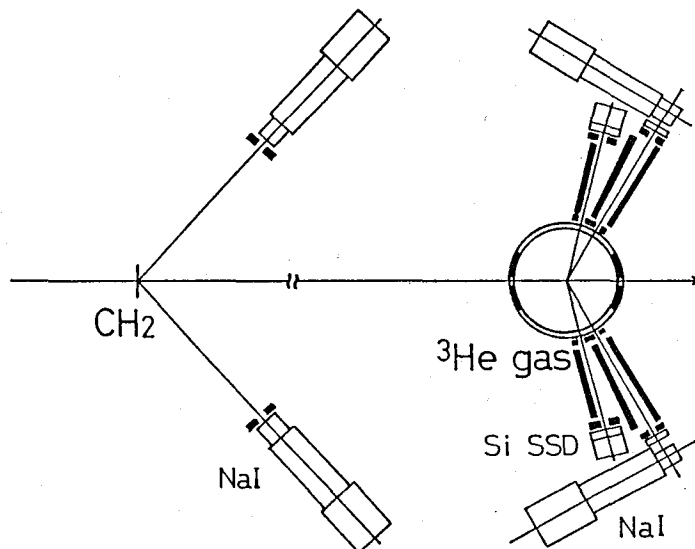


Fig. 1. Experimental set up for the  ${}^3\text{He}(p, d)2p$  reaction at  $E_p=65$  MeV.

set at  $\theta=47.5^\circ$ . The average beam polarization was about 85% during the experiment. In the down stream,  ${}^3\text{He}$  gas target pressurized at 2.5 atm was set in a large chamber. Used gas cell was 16 cm diameter with  $10\text{ }\mu\text{m}$  Havar windows. Two counter telescopes consisted of a  $300\text{ }\mu\text{m}$  thick Si  $\Delta E$  counter and a 25.4 mm thick NaI(Tl) E counter were set on both side of the beam and used for the forward angle measurements. And other two counter telescopes consisted of a  $200\text{ }\mu\text{m}$  thick Si  $\Delta E$  counter and a 5 mm thick Si E counter were set on both side of the beam and used for the backward angle measurements. Scattered deuterons from  ${}^3\text{He}$  were detected with these counters. Measurements were done from  $15^\circ$  to  $75^\circ$  in the laboratory system. Overall energy resolution was better than 700 keV. Signals from the detectors were accumulated through a first slow circuit system, a raw data processor and a PDP 11/40 system on magnetic tapes. Data reductions were done using the FACOM M-200 computer of RCNP and the FACOM M-180 computer of Kyoto University.

### 3. RESULTS AND DISCUSSIONS

Continuum energy spectra of the scattered deuteron were obtained and shown in the figs. 2a-2c. Left side figures correspond to the ones at spin up. Right side ones correspond to those at spin down. Measured laboratory angles are presented in the figures. Because of the spread of the proton peaks scattered elastically, foots of them are mixed with the deuteron spectra and appeared in high energy side in the figures at small angles. For other energy region, the separation of proton and deuteron is good enough. Continuum spectra start at 5.5 MeV down from the elastic peak. In the spectra at forward angles, large enhancements are seen near the breakup threshold energy. Residual nucleus is di-proton. So the enhancements seem to be caused from the pp FSI

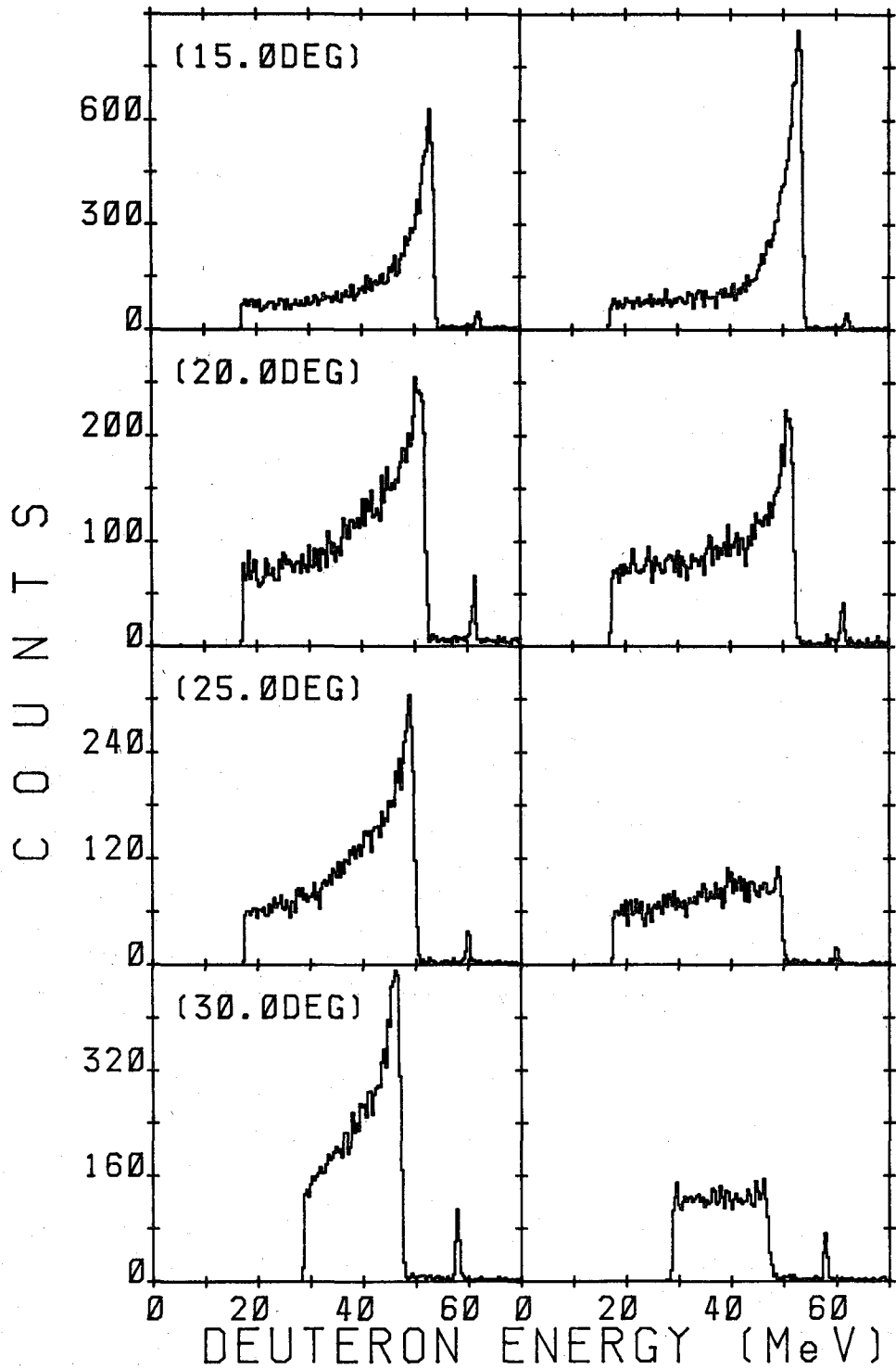


Fig. 2a. Continuum deuteron spectra from  $\theta_{lab}=15^\circ$  to  $30^\circ$

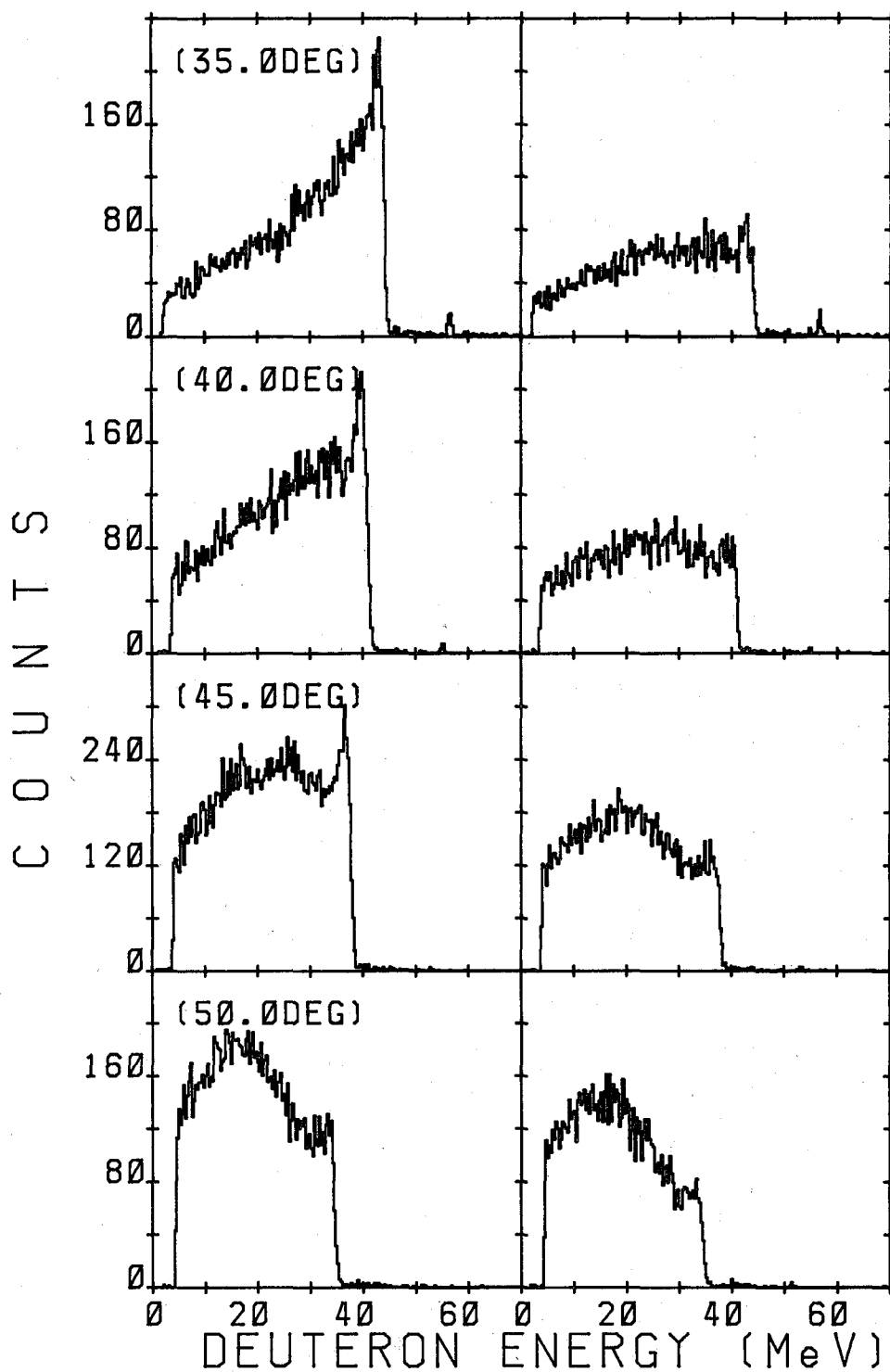


Fig. 2b. Continuum deuteron spectra from  $\theta_{lab}=35^\circ$  to  $50^\circ$

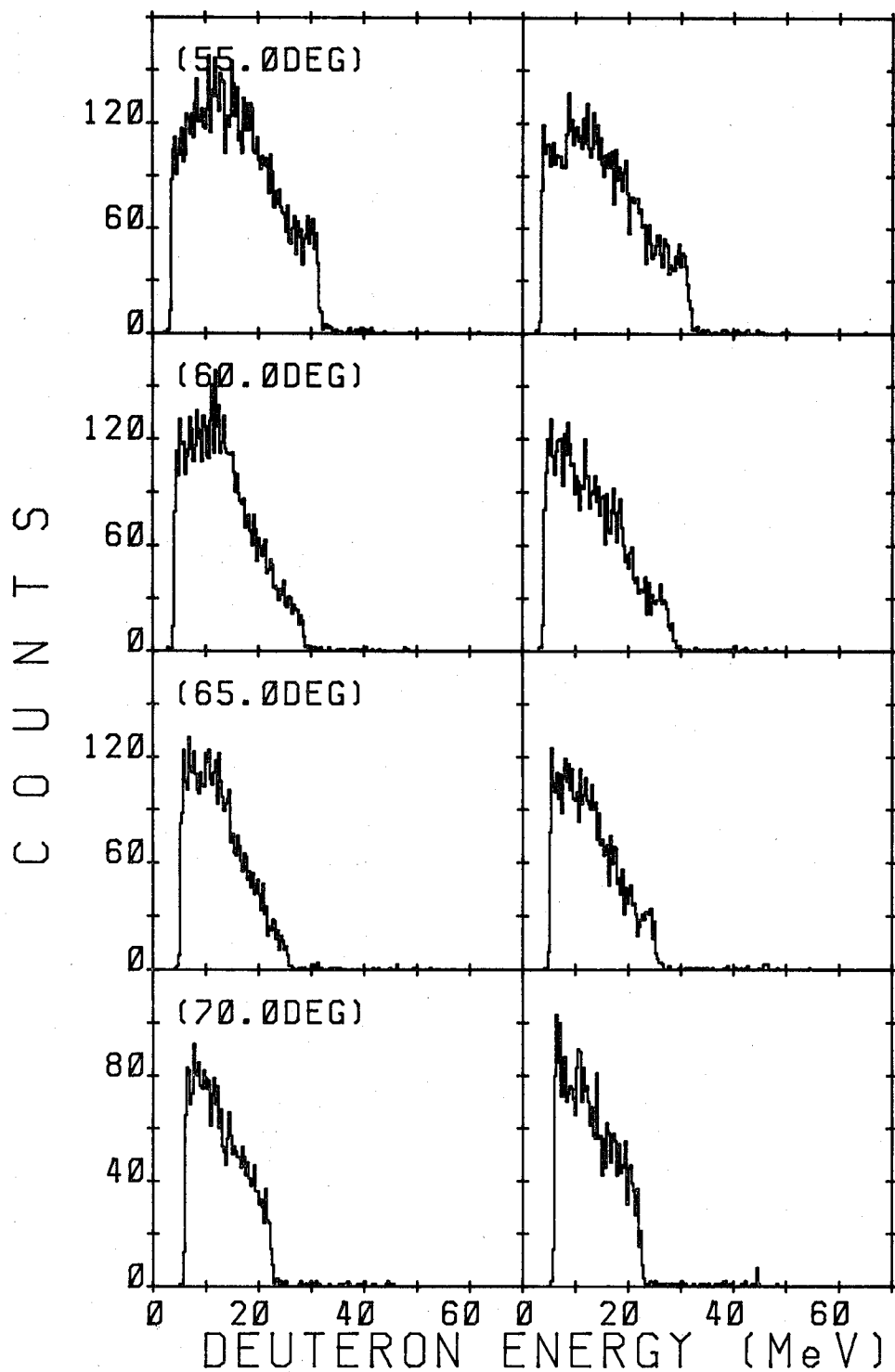


Fig. 2c. Continuum deuteron spectra from  $\theta_{lab}=55^\circ$  to  $70^\circ$

( $1S_0$ ). Continuum spectra were divided into several relative energy ( $E_{\text{rel}}$ ) bins of pp. Angular distributions of the differential cross sections  $d\sigma/d\Omega$  dE and the analyzing powers  $A_y$  in the region of  $0.0 \text{ MeV} < E_{\text{rel}} < 2.0 \text{ MeV}$ , where the pp FSI was mainly effective, were obtained and shown by using solid circles in figs. 3 and 4. Open circles show the differential cross sections and the analyzing powers in the region of  $15.0 \text{ MeV} < E_{\text{rel}} < 17.0 \text{ MeV}$  where the phase space seems to be dominant. As seen in the figure, the angular distribution of the differential cross sections for the phase space region is almost structureless. On the other hand, for the FSI region, the differential cross sections decrease rapidly with increasing angles and have a Coulomb nuclear interference dip and a valley at near  $\theta_{\text{lab}} = 100^\circ$ . As for the analyzing powers, the angular distribution for the phase space region have a bump at forward angles. In general, the phase space has no asymmetry. Then this bump may be caused that some reaction mechanisms such as Quasifree Scattering are included in this phase space region. Analyzing powers for the FSI region have a large positive bump at forward angular region and grows to negative value with decreasing angles. According to the double scattering calculation in the FSI region<sup>4)</sup>, the FSI occurs at the second stage of the reaction mechanism and the angular distribution depends mainly on the first two body interaction. In this case, considering  $p+{}^3\text{He}$  system as  $p+(p+d)$  or  $p+(n+2p)$ , the first two body interaction reaction can be caused from the deuteron knockout reaction or the neutron pickup reaction. According to the deuteron knockout reaction, the angular distribution for the  ${}^3\text{He}(p,d)2p$  reaction will be resemble to the  ${}^2\text{H}(p,d)p$  reaction. Figures 5 and 6 show the angular distribution of the differential

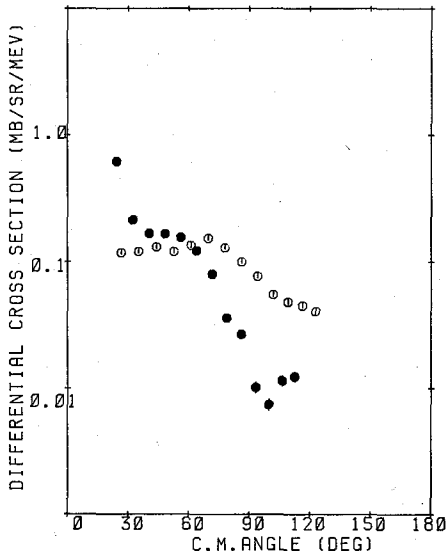


Fig. 3. Angular distributions of the differential cross sections for the  ${}^3\text{He}(p,d)2p$  reaction. Solid circles correspond to the region of  $0 \text{ MeV} < E_{\text{rel}} < 2 \text{ MeV}$ . Open circles correspond to the region of  $15 \text{ MeV} < E_{\text{rel}} < 17 \text{ MeV}$ .

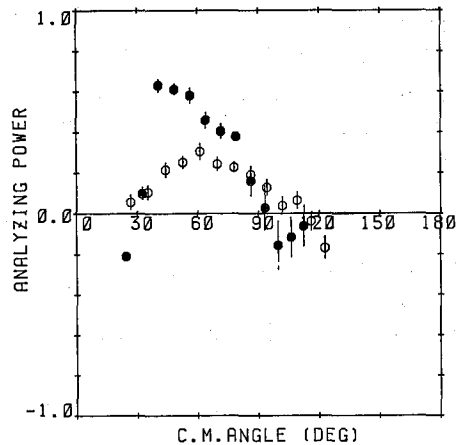


Fig. 4. Angular distributions of the analyzing powers for the  ${}^3\text{He}(p,d)2p$  reaction. Solid circles correspond to the region of  $0 \text{ MeV} < E_{\text{rel}} < 2 \text{ MeV}$ . Open circles correspond to the region of  $15 \text{ MeV} < E_{\text{rel}} < 17 \text{ MeV}$ .

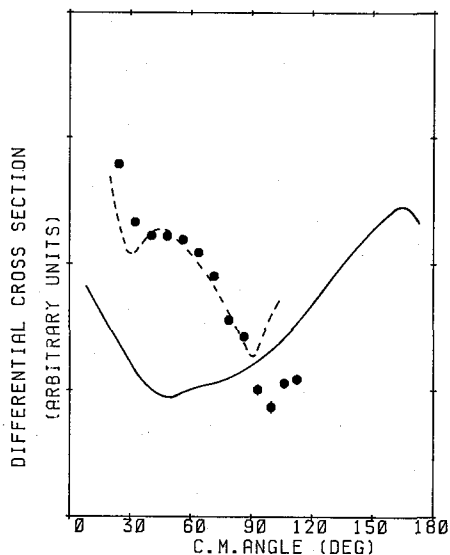


Fig. 5. Solid circles show the angular distributions of the differential cross sections for the  ${}^3\text{He}(p,d)2p$  reaction in the pp FSI region at  $E_p=65$  MeV. Solid curve shows those for the  ${}^2\text{H}(p,d)p$  reaction at  $E_p=65$  MeV. Dashed curve shows those for the  ${}^3\text{H}(p,d)d$  reaction at  $E_p=65$  MeV.

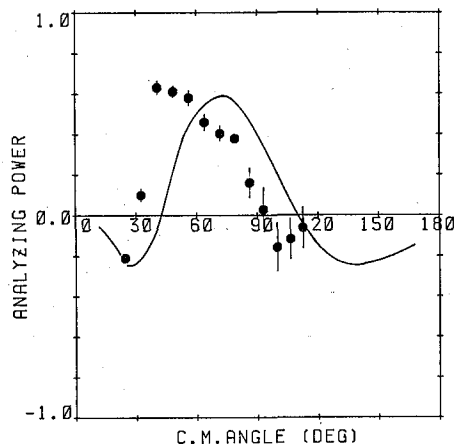


Fig. 6. Solid circles show the angular distributions of the analyzing powers for the  ${}^3\text{He}(p,d)2p$  reaction in the pp FSI region at  $E_p=65$  MeV. Solid curve shows those for the  ${}^2\text{H}(p,d)p$  reaction at  $E_p=65$  MeV.

cross sections and the analyzing powers for the  ${}^3\text{He}(p,d)2p$  reaction with solid circles and for the  ${}^2\text{H}(p,d)p$  reaction with solid curves. Data for the  ${}^2\text{H}(p,d)p$  reaction are derived from the ones for the  ${}^2\text{H}(p,p){}^2\text{H}$  scattering at  $E_p=65$  MeV<sup>2)</sup>. Comparing both reactions, the differential cross sections are quite different and the analyzing powers are shifted. Therefore, perhaps the first two body interaction is not the deuteron knockout reaction. Dashed line in fig. 5 shows the cross sections for the  ${}^3\text{H}(p,d){}^2\text{H}$  reaction at  $E_p=65$  MeV which are extrapolated from the ones for the  ${}^2\text{H}(d,p){}^3\text{H}$  reaction at  $E_d=77$  MeV and 85 MeV<sup>3)</sup>. The angular distribution of the cross sections is quite similar to the one for the FSI region except for backward angular region. Probably, for both reactions, the neutron pickup reaction is dominant in the forward angular region. The difference of the absolute cross sections will depend on the difference of the configuration of  $n+2p$  for  ${}^3\text{He}$  and  $n+d$  for triton.

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